Thomas Jones CS5567-0002 Final Project

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| --- | --- |
| Link | URL |
| Video |  |
| Baseline Model | <https://colab.research.google.com/drive/1lSOuwIp4zi9JfrJ-a8LeOJ13a-9QMviJ?usp=sharing> |
| V1 Custom | <https://colab.research.google.com/drive/1xQ86eHylA6O3fI-w9yu7G-m4d-0EogGd?usp=sharing> |
| V2 Custom | <https://colab.research.google.com/drive/12_aIMi6306HBtr0ojeCqSJaux7U4BLaH> |
| V3 Custom | <https://colab.research.google.com/drive/1-TL8HVl13PCGpdr4_z_HvOxpcvtYt-KO> |
| V4 Custom | <https://colab.research.google.com/drive/19faXAUjaDLwxPfAVuk2c1EF_V2xFIn71?usp=sharing> |
| V5 Custom | <https://colab.research.google.com/drive/1XDhFS5t0bqUZ-zHigSDRPezXxJKi1zHx?usp=sharing> |
| V6 Custom | <https://colab.research.google.com/drive/1s7Yix4sV5dVreycfeM5VqZXa0j4LsB3d?usp=sharing> |
| Resnet50 | <https://colab.research.google.com/drive/1_gxbJIjZrfiB27OYWBZUyhQGi6HzhU2X?usp=sharing> |
| VGG19 | <https://colab.research.google.com/drive/1QagxXm3oMVZocYtEtSdLe-r4FCwPGwAJ?usp=sharing> |
| Video Transformer | <https://colab.research.google.com/drive/1RlkJi2RrnI53Aw0741i7WY7X1-41QbYO?usp=sharing> |

# Overview

The final project consisted of two main parts, with the first part being an exploration of color image recognition across a number of custom networks along with ResNet50 and VGG-19.

# Part A – Feature Layer with Adjacent Tasks

The experiment modeled a number of different overall topologies for training. An initial 3-layer CNN topology was used as a baseline upon which further topologies were explored.

Each of the linked notebooks consists of a method called build\_baseline\_model which is where the transfer layer was defined. The overall scripts only vary by this method except for ResNet50 and VGG19 which did not include experiment 1.

## Topologies Used

### Baseline Model

A screenshot of a computer

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### Custom Model 1

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### Custom Model 2

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### Custom Model 3

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### Custom Model 4

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### Custom Model 5

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### Custom Model 6

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Description automatically generated

This model was the same as 5 except it was trained with a random rotation.

## Experiment 1

Each of the custom models was trained over the entire CIFAR10 training set and validated against the CIFAR10 test set, i.e. the train-test split is provided by the base dataset. Training was done with a maximum of 300 epochs with early stopping implemented as well as learning rate reduction. None of the training sessions made it to 300 epochs.

The default Adam optimizer (lr=0.001,etc.) was used for all training sessions.

The inner model was headed with three Dense layers. The first dense layer was 128 units, the second was 64 units with a dropout between them, and an output layer with 10 units. A batch normalization layer was include between the final and next to final layer.

The “wrapper” network included a 2D global average pooling layer as input from the headless model.

A screen shot of a computer code

Description automatically generated

The activation for all neurons was ReLU for this project.

A batch size of 64 was used for this experiment and all other experiments.

A computer code with black and red text

Description automatically generated

### Baseline Model Results

A graph of a training and validation model

Description automatically generated with medium confidence

Epoch 147/300

**1563/1563** ━━━━━━━━━━━━━━━━━━━━ **5s** 3ms/step - accuracy: 0.9896 - loss: 0.0284 - val\_accuracy: 0.8604 - val\_loss: 0.6684 - learning\_rate: 1.5625e-05

precision recall f1-score support

0 0.86 0.89 0.88 1000

1 0.93 0.93 0.93 1000

2 0.83 0.76 0.79 1000

3 0.74 0.72 0.73 1000

4 0.83 0.87 0.85 1000

5 0.78 0.80 0.79 1000

6 0.83 0.93 0.87 1000

7 0.95 0.85 0.89 1000

8 0.92 0.93 0.92 1000

9 0.93 0.90 0.92 1000

accuracy 0.86 10000

macro avg 0.86 0.86 0.86 10000

weighted avg 0.86 0.86 0.86 10000

### Custom Model 1 Results

A graph of a training and validation model

Description automatically generated with medium confidence

Epoch 109/300

**1563/1563** ━━━━━━━━━━━━━━━━━━━━ **6s** 4ms/step - accuracy: 0.9960 - loss: 0.0121 - val\_accuracy: 0.8990 - val\_loss: 0.5629 - learning\_rate: 1.5625e-05

precision recall f1-score support

0 0.93 0.90 0.91 1000

1 0.96 0.95 0.95 1000

2 0.90 0.81 0.85 1000

3 0.79 0.81 0.80 1000

4 0.86 0.94 0.90 1000

5 0.87 0.83 0.85 1000

6 0.87 0.95 0.91 1000

7 0.96 0.92 0.94 1000

8 0.92 0.96 0.94 1000

9 0.95 0.93 0.94 1000

accuracy 0.90 10000

macro avg 0.90 0.90 0.90 10000

weighted avg 0.90 0.90 0.90 10000

### Custom Model 2 Results

A graph of a graph of a graph

Description automatically generated with medium confidence

Epoch 122/300

**1563/1563** ━━━━━━━━━━━━━━━━━━━━ **8s** 5ms/step - accuracy: 0.9978 - loss: 0.0076 - val\_accuracy: 0.8998 - val\_loss: 0.5919 - learning\_rate: 1.5625e-05

precision recall f1-score support

0 0.92 0.90 0.91 1000

1 0.96 0.95 0.96 1000

2 0.90 0.81 0.85 1000

3 0.83 0.79 0.81 1000

4 0.85 0.92 0.88 1000

5 0.83 0.87 0.85 1000

6 0.88 0.95 0.91 1000

7 0.95 0.92 0.94 1000

8 0.93 0.95 0.94 1000

9 0.96 0.93 0.94 1000

accuracy 0.90 10000

macro avg 0.90 0.90 0.90 10000

weighted avg 0.90 0.90 0.90 10000

### Custom Model 3 Results

A graph of a graph of a training and validation

Description automatically generated with medium confidence

Epoch 101/300

**1563/1563** ━━━━━━━━━━━━━━━━━━━━ **13s** 8ms/step - accuracy: 0.9976 - loss: 0.0071 - val\_accuracy: 0.9086 - val\_loss: 0.4832 - learning\_rate: 6.2500e-05

precision recall f1-score support

0 0.91 0.92 0.92 1000

1 0.96 0.96 0.96 1000

2 0.88 0.86 0.87 1000

3 0.81 0.80 0.80 1000

4 0.87 0.94 0.90 1000

5 0.88 0.84 0.86 1000

6 0.90 0.95 0.92 1000

7 0.96 0.93 0.94 1000

8 0.95 0.96 0.95 1000

9 0.97 0.93 0.95 1000

accuracy 0.91 10000

macro avg 0.91 0.91 0.91 10000

weighted avg 0.91 0.91 0.91 10000

### Custom Model 4 Results

A graph of a graph of a training and validation

Description automatically generated with medium confidence

Epoch 121/300

**1563/1563** ━━━━━━━━━━━━━━━━━━━━ **12s** 8ms/step - accuracy: 0.9979 - loss: 0.0078 - val\_accuracy: 0.9096 - val\_loss: 0.4920 - learning\_rate: 1.5625e-05

precision recall f1-score support

0 0.89 0.94 0.92 1000

1 0.96 0.95 0.95 1000

2 0.90 0.85 0.87 1000

3 0.82 0.81 0.82 1000

4 0.89 0.92 0.90 1000

5 0.88 0.86 0.87 1000

6 0.91 0.94 0.92 1000

7 0.95 0.94 0.95 1000

8 0.94 0.95 0.95 1000

9 0.96 0.94 0.95 1000

accuracy 0.91 10000

macro avg 0.91 0.91 0.91 10000

weighted avg 0.91 0.91 0.91 10000

### Custom Model 5 Results

A graph of a training and validation model

Description automatically generated with medium confidence

Epoch 128/300

**1563/1563** ━━━━━━━━━━━━━━━━━━━━ **14s** 9ms/step - accuracy: 0.9977 - loss: 0.0075 - val\_accuracy: 0.9074 - val\_loss: 0.5052 - learning\_rate: 3.9063e-06

precision recall f1-score support

0 0.91 0.93 0.92 1000

1 0.96 0.95 0.96 1000

2 0.88 0.85 0.86 1000

3 0.82 0.81 0.82 1000

4 0.86 0.92 0.89 1000

5 0.89 0.83 0.86 1000

6 0.91 0.94 0.92 1000

7 0.94 0.95 0.94 1000

8 0.94 0.96 0.95 1000

9 0.95 0.94 0.94 1000

accuracy 0.91 10000

macro avg 0.91 0.91 0.91 10000

weighted avg 0.91 0.91 0.91 10000

### Custom Model 6 Results

A graph of a training and validation model

Description automatically generated with medium confidence

Epoch 140/300

**1563/1563** ━━━━━━━━━━━━━━━━━━━━ **38s** 24ms/step - accuracy: 0.9830 - loss: 0.0487 - val\_accuracy: 0.9076 - val\_loss: 0.3674 - learning\_rate: 7.8125e-06

precision recall f1-score support

0 0.89 0.94 0.91 1000

1 0.95 0.96 0.96 1000

2 0.88 0.88 0.88 1000

3 0.83 0.81 0.82 1000

4 0.90 0.91 0.90 1000

5 0.90 0.82 0.86 1000

6 0.90 0.95 0.93 1000

7 0.93 0.94 0.94 1000

8 0.94 0.94 0.94 1000

9 0.94 0.94 0.94 1000

accuracy 0.91 10000

macro avg 0.91 0.91 0.91 10000

weighted avg 0.91 0.91 0.91 10000

### Overall Results Observations

Accuracy peaked at 91% for the most complicated topologies tested. All the networks seemed to have issues with classes 2, 3, and 5 which were birds, cats, and dogs and particularly cats and dogs were consistently the lowest. Given the similarity between the two this is not a surprising result.

If we look at the confusion matrix from the baseline model,

[[900 7 25 12 7 4 5 5 23 12]

[ 8 926 3 6 1 1 4 1 6 44]

[ 37 1 796 32 48 30 43 7 4 2]

[ 19 2 38 702 32 128 53 15 4 7]

[ 5 1 37 33 849 24 33 14 4 0]

[ 5 1 20 86 25 832 14 14 0 3]

[ 3 1 22 30 8 16 914 3 2 1]

[ 12 0 16 25 34 39 4 867 0 3]

[ 43 5 3 7 0 2 9 1 917 13]

[ 18 43 6 4 1 4 6 6 11 901]]

We indeed see that dogs were confused with cats in 128 cases while cats in 86 cases, both the majority of misclassifications for those instances. These results were consistent across all experiments.

Given the organic nature of those classes the results are not surprising.

## Experiment 2

After initial training against CIFAR10 the inner model was saved.

### CIFAR100

A new model head was created following the same pattern as was used or training except the dense layers which were 256, 128, and 100 respectively.

The inner models were frozen except for the batch normalization layers.

A screenshot of a computer program

Description automatically generated

### TinyImageNet

A new model head was created following the same pattern as was used for training except for the dense layers which were 512, 128, and 200 respectively.

The inner models were frozen except for the batch normalization layers.

A screenshot of a computer program

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### Baseline Model Results

A graph of training and validation model

Description automatically generated

Epoch 120/300

**1563/1563** ━━━━━━━━━━━━━━━━━━━━ **4s** 3ms/step - accuracy: 0.5411 - loss: 1.6433 - val\_accuracy: 0.5130 - val\_loss: 1.8446 - learning\_rate: 1.9531e-06

A graph of a graph of a training model

Description automatically generated with medium confidence

Epoch 138/300

**3125/3125** ━━━━━━━━━━━━━━━━━━━━ **8s** 2ms/step - accuracy: 0.3939 - loss: 2.4592 - val\_accuracy: 0.3059 - val\_loss: 3.1008 - learning\_rate: 7.8125e-06

### Custom Model 1 Results

A graph of a training model

Description automatically generated with medium confidence

Epoch 106/300

**1563/1563** ━━━━━━━━━━━━━━━━━━━━ **5s** 3ms/step - accuracy: 0.5103 - loss: 1.7492 - val\_accuracy: 0.4025 - val\_loss: 2.3173 - learning\_rate: 3.1250e-05

A graph of a graph of a graph

Description automatically generated with medium confidence

Epoch 145/300

**3125/3125** ━━━━━━━━━━━━━━━━━━━━ **10s** 3ms/step - accuracy: 0.3604 - loss: 2.6295 - val\_accuracy: 0.2104 - val\_loss: 3.6554 - learning\_rate: 7.8125e-06

### Custom Model 2 Results

A screenshot of a graph

Description automatically generated

Epoch 104/300

**1563/1563** ━━━━━━━━━━━━━━━━━━━━ **6s** 4ms/step - accuracy: 0.3940 - loss: 2.2531 - val\_accuracy: 0.0873 - val\_loss: 4.3795 - learning\_rate: 3.1250e-05

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Description automatically generated

Epoch 107/300

**3125/3125** ━━━━━━━━━━━━━━━━━━━━ **12s** 4ms/step - accuracy: 0.2413 - loss: 3.2607 - val\_accuracy: 0.0278 - val\_loss: 5.4541 - learning\_rate: 1.5625e-05

### Custom Model 3

A graph of a graph of a graph

Description automatically generated with medium confidence

Epoch 109/300

**1563/1563** ━━━━━━━━━━━━━━━━━━━━ **8s** 5ms/step - accuracy: 0.3515 - loss: 2.4356 - val\_accuracy: 0.2303 - val\_loss: 3.0962 - learning\_rate: 1.5625e-05

A graph of a graph of a graph

Description automatically generated with medium confidence

Epoch 132/300

**3125/3125** ━━━━━━━━━━━━━━━━━━━━ **16s** 5ms/step - accuracy: 0.2110 - loss: 3.4131 - val\_accuracy: 0.1073 - val\_loss: 4.2688 - learning\_rate: 3.9063e-06

### Custom Model 4 Results

A graph of different colored lines

Description automatically generated

Epoch 94/300

**1563/1563** ━━━━━━━━━━━━━━━━━━━━ **9s** 5ms/step - accuracy: 0.3481 - loss: 2.4295 - val\_accuracy: 0.2996 - val\_loss: 2.7204 - learning\_rate: 6.2500e-05

A graph of a graph of a graph

Description automatically generated with medium confidence

Epoch 109/300

**3125/3125** ━━━━━━━━━━━━━━━━━━━━ **17s** 5ms/step - accuracy: 0.2063 - loss: 3.4317 - val\_accuracy: 0.1406 - val\_loss: 3.9559 - learning\_rate: 3.1250e-05

### Custom Model 5 Results

A graph of a graph of a graph of a graph of a graph of a graph of a graph of a graph of a graph of a graph of a graph of a graph of a graph of

Description automatically generated

Epoch 102/300

**1563/1563** ━━━━━━━━━━━━━━━━━━━━ **10s** 6ms/step - accuracy: 0.3472 - loss: 2.4582 - val\_accuracy: 0.3277 - val\_loss: 2.5738 - learning\_rate: 6.2500e-05

A graph of a training and validation model

Description automatically generated with medium confidence

Epoch 135/300

**3125/3125** ━━━━━━━━━━━━━━━━━━━━ **18s** 6ms/step - accuracy: 0.2107 - loss: 3.4309 - val\_accuracy: 0.1788 - val\_loss: 3.6722 - learning\_rate: 3.1250e-05

### Custom Model 6 Results

A screenshot of a graph

Description automatically generated

Epoch 134/300

**1563/1563** ━━━━━━━━━━━━━━━━━━━━ **9s** 6ms/step - accuracy: 0.4183 - loss: 2.1308 - val\_accuracy: 0.3477 - val\_loss: 2.5036 - learning\_rate: 1.5625e-05

A graph of a graph of a graph

Description automatically generated with medium confidence

Epoch 123/300

**3125/3125** ━━━━━━━━━━━━━━━━━━━━ **17s** 5ms/step - accuracy: 0.2577 - loss: 3.1444 - val\_accuracy: 0.1793 - val\_loss: 3.7758 - learning\_rate: 3.1250e-05

### ResNet50 Results

A graph of a training model

Description automatically generated with medium confidence

Epoch 82/300

**1563/1563** ━━━━━━━━━━━━━━━━━━━━ **44s** 28ms/step - accuracy: 0.9988 - loss: 0.0036 - val\_accuracy: 0.9578 - val\_loss: 0.2564 - learning\_rate: 6.2500e-05

precision recall f1-score support

0 0.97 0.96 0.96 1000

1 0.97 0.98 0.98 1000

2 0.97 0.95 0.96 1000

3 0.92 0.91 0.92 1000

4 0.95 0.96 0.96 1000

5 0.92 0.93 0.93 1000

6 0.97 0.97 0.97 1000

7 0.96 0.97 0.97 1000

8 0.96 0.99 0.97 1000

9 0.98 0.96 0.97 1000

accuracy 0.96 10000

macro avg 0.96 0.96 0.96 10000

weighted avg 0.96 0.96 0.96 10000

A graph of a training and validation model

Description automatically generated with medium confidence

Epoch 125/300

**1563/1563** ━━━━━━━━━━━━━━━━━━━━ **45s** 29ms/step - accuracy: 0.9949 - loss: 0.0156 - val\_accuracy: 0.8032 - val\_loss: 1.4717 - learning\_rate: 7.8125e-06

A graph of a graph of a graph

Description automatically generated with medium confidence

Epoch 177/300

**3125/3125** ━━━━━━━━━━━━━━━━━━━━ **85s** 27ms/step - accuracy: 0.9896 - loss: 0.0327 - val\_accuracy: 0.6314 - val\_loss: 3.6529 - learning\_rate: 3.9063e-06

### VGG-19 Model Results

A graph of a graph of a graph of a graph of a graph of a graph of a graph of a graph of a graph of a graph of a graph of a graph of a graph of

Description automatically generated

Epoch 69/300

**1563/1563** ━━━━━━━━━━━━━━━━━━━━ **30s** 19ms/step - accuracy: 0.5955 - loss: 1.1394 - val\_accuracy: 0.4767 - val\_loss: 1.4172 - learning\_rate: 3.1250e-05

precision recall f1-score support

0 0.84 0.44 0.58 1000

1 0.81 0.65 0.72 1000

2 0.77 0.17 0.27 1000

3 0.19 0.92 0.31 1000

4 0.62 0.32 0.42 1000

5 0.62 0.23 0.34 1000

6 0.86 0.29 0.43 1000

7 0.87 0.39 0.54 1000

8 0.65 0.74 0.69 1000

9 0.77 0.63 0.69 1000

accuracy 0.48 10000

macro avg 0.70 0.48 0.50 10000

weighted avg 0.70 0.48 0.50 10000

A graph of a graph of a graph

Description automatically generated with medium confidence

Epoch 123/300

**1563/1563** ━━━━━━━━━━━━━━━━━━━━ **31s** 20ms/step - accuracy: 0.3346 - loss: 2.5760 - val\_accuracy: 0.3443 - val\_loss: 2.5590 - learning\_rate: 7.8125e-06

A graph of a graph of a graph

Description automatically generated with medium confidence

Epoch 129/300

**3125/3125** ━━━━━━━━━━━━━━━━━━━━ **55s** 18ms/step - accuracy: 0.2308 - loss: 3.3945 - val\_accuracy: 0.2262 - val\_loss: 3.4752 - learning\_rate: 7.8125e-06

### Overall Results Discussion

All the results followed a common pattern.

Where the Model 2 setup performed poorly and VGG19 didn’t perform any better than Model 6.

It is very likely that the poor transfer performance of Model 2 was due to the use of 50% dropouts in the last layer of the model where the higher level features live. It is also possible that this explains the poorer performance of Model 1 relative to the baseline model since the last layer there had a 30% dropout.

The use of increasing values of dropout was part of the planned architecture and would be revisited in later implementations, perhaps as a consistent, topology wide hyper-parameter as opposed to something specific to each layer.

The performance of ResNet was expected, however the poor showing of VGG is a mystery as of this report and would need to be further explored.

## Experiment 3

This experiment utilized the saved model from experiment one and then fine-tuned the model against the Tinynet dataset. The inner model was unfrozen.

A screenshot of a computer program

Description automatically generated

### Baseline Model

A graph of a graph of a graph

Description automatically generated with medium confidence

Epoch 203/300

**3125/3125** ━━━━━━━━━━━━━━━━━━━━ **9s** 3ms/step - accuracy: 0.6773 - loss: 1.1341 - val\_accuracy: 0.3913 - val\_loss: 3.0508 - learning\_rate: 7.8125e-06

### Custom Model 1

A graph of a graph of a graph

Description automatically generated with medium confidence

Epoch 207/300

**3125/3125** ━━━━━━━━━━━━━━━━━━━━ **13s** 4ms/step - accuracy: 0.7686 - loss: 0.7696 - val\_accuracy: 0.4393 - val\_loss: 3.1862 - learning\_rate: 3.1250e-05

### Custom Model 2

A graph of a graph of a graph

Description automatically generated with medium confidence

Epoch 239/300

**3125/3125** ━━━━━━━━━━━━━━━━━━━━ **16s** 5ms/step - accuracy: 0.7909 - loss: 0.6975 - val\_accuracy: 0.4113 - val\_loss: 3.6299 - learning\_rate: 7.8125e-06

### Custom Model 3

A graph of a graph of a graph

Description automatically generated with medium confidence

Epoch 300/300

**3125/3125** ━━━━━━━━━━━━━━━━━━━━ **23s** 7ms/step - accuracy: 0.8083 - loss: 0.6341 - val\_accuracy: 0.4697 - val\_loss: 3.2608 - learning\_rate: 6.2500e-05

### Custom Model 4

A graph of a graph of a graph

Description automatically generated with medium confidence

Epoch 300/300

**3125/3125** ━━━━━━━━━━━━━━━━━━━━ **24s** 8ms/step - accuracy: 0.8034 - loss: 0.6521 - val\_accuracy: 0.4681 - val\_loss: 3.2455 - learning\_rate: 6.2500e-05

### Custom Model 5

A graph of a graph of a graph

Description automatically generated with medium confidence

Epoch 232/300

**3125/3125** ━━━━━━━━━━━━━━━━━━━━ **25s** 8ms/step - accuracy: 0.7660 - loss: 0.7929 - val\_accuracy: 0.4607 - val\_loss: 3.0141 - learning\_rate: 1.9531e-06

### Custom Model 6

A graph of a graph of a graph

Description automatically generated with medium confidence

Epoch 300/300

**3125/3125** ━━━━━━━━━━━━━━━━━━━━ **68s** 22ms/step - accuracy: 0.7805 - loss: 0.7495 - val\_accuracy: 0.4428 - val\_loss: 3.2535 - learning\_rate: 1.5625e-05

### Resnet50 Model

A graph of a graph of a graph

Description automatically generated with medium confidence

Epoch 166/300

**3125/3125** ━━━━━━━━━━━━━━━━━━━━ **119s** 38ms/step - accuracy: 0.9997 - loss: 7.9908e-04 - val\_accuracy: 0.3852 - val\_loss: 6.7637 - learning\_rate: 1.2207e-07

### VGG19 Model

A graph of a training model

Description automatically generated with medium confidence

Epoch 49/300

**3125/3125** ━━━━━━━━━━━━━━━━━━━━ **194s** 62ms/step - accuracy: 0.0045 - loss: 5.3017 - val\_accuracy: 0.0050 - val\_loss: 5.3002 - learning\_rate: 5.0000e-04

### Overall Results Discussion

None of the networks were able to reach a validation/test accuracy above 50% during training. It is possible that other hyper-parameter exploration would be necessary given the larger size of the dataset. One of the most interesting factors was that VGG19 failed to train properly, likely suffering a gradient explosion.

## Experiment 4

Once the full network was trained against the Tiny Image dataset, the inner model was frozen and re-headed.

A screenshot of a computer program

Description automatically generated

### Baseline Model Results

A graph of a training and validation model

Description automatically generated with medium confidence

Epoch 62/300

**1563/1563** ━━━━━━━━━━━━━━━━━━━━ **4s** 3ms/step - accuracy: 0.8364 - loss: 0.4614 - val\_accuracy: 0.8275 - val\_loss: 0.5084 - learning\_rate: 6.2500e-05

### Custom Model 1 Results

A graph of a training and validation model

Description automatically generated with medium confidence

Epoch 66/300

**1563/1563** ━━━━━━━━━━━━━━━━━━━━ **5s** 3ms/step - accuracy: 0.8640 - loss: 0.3844 - val\_accuracy: 0.8637 - val\_loss: 0.3984 - learning\_rate: 3.1250e-05

### Custom Model 2 Results

A graph of different colored lines

Description automatically generated

Epoch 73/300

**1563/1563** ━━━━━━━━━━━━━━━━━━━━ **6s** 4ms/step - accuracy: 0.8428 - loss: 0.4421 - val\_accuracy: 0.7927 - val\_loss: 0.6092 - learning\_rate: 3.1250e-05

### Custom Model 3 Results

A graph of a training and validation model

Description automatically generated with medium confidence

Epoch 58/300

**1563/1563** ━━━━━━━━━━━━━━━━━━━━ **8s** 5ms/step - accuracy: 0.8343 - loss: 0.4747 - val\_accuracy: 0.8474 - val\_loss: 0.4427 - learning\_rate: 3.1250e-05

### Custom Model 4 Results

A graph of a training and validation model

Description automatically generated with medium confidence

Epoch 54/300

**1563/1563** ━━━━━━━━━━━━━━━━━━━━ **8s** 5ms/step - accuracy: 0.8406 - loss: 0.4667 - val\_accuracy: 0.8564 - val\_loss: 0.4185 - learning\_rate: 6.2500e-05

### Custom Model 5 Results

A graph of different colored lines

Description automatically generated

Epoch 55/300

**1563/1563** ━━━━━━━━━━━━━━━━━━━━ **9s** 6ms/step - accuracy: 0.8415 - loss: 0.4617 - val\_accuracy: 0.8525 - val\_loss: 0.4287 - learning\_rate: 6.2500e-05

### Custom Model 6 Results

A graph of different colored lines

Description automatically generated

Epoch 70/300

**1563/1563** ━━━━━━━━━━━━━━━━━━━━ **9s** 6ms/step - accuracy: 0.8680 - loss: 0.3754 - val\_accuracy: 0.8538 - val\_loss: 0.4242 - learning\_rate: 3.1250e-05

### ResNet50 Results

A graph of a graph

Description automatically generated with medium confidence

Epoch 108/300

**1563/1563** ━━━━━━━━━━━━━━━━━━━━ **22s** 14ms/step - accuracy: 0.9920 - loss: 0.0225 - val\_accuracy: 0.7610 - val\_loss: 1.4768 - learning\_rate: 1.5625e-05

### VGG-19 Results

A graph of a graph of a graph of a graph of a graph of a graph of a graph of a graph of a graph of a graph of a graph of a graph of a graph of

Description automatically generated

Epoch 41/300

**1563/1563** ━━━━━━━━━━━━━━━━━━━━ **29s** 19ms/step - accuracy: 0.0984 - loss: 2.3026 - val\_accuracy: 0.1000 - val\_loss: 2.3026 - learning\_rate: 9.7656e-07

### Overall Results Discussion

Retraining on the CIFAR10 dataset showed some loss of accuracy, typically around 5% for each of the models. The exceptions were ResNet and VGG19 but as discussed previously, the VGG19 model became unstable. Further exploration of ResNet performance would be required to determine proper retraining hyper-parameters considering the previous performance characteristic.

## Overall Conclusion

Developing a proper headless model, from the differing, sometime perplexing, results shown here is a complex task. Not only would such a model need to be developed properly to have a high accuracy on the initial dataset, but it would also have to be robust to fine-tuning and such a model would need to include clear parameters for that hyper-tuning. For example, consider the differences in performance for the Model 2 topology. Initial training results showed little difference between it and the Model 3 topology but when re-trained it performed significantly worse.

This need for specificity for fine-tuning is even more obvious for VGG19. The general framework used for all the topologies is clearly not appropriate for that pre-trained model.